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EP 0616240 A EP 0433999 A EP 0421432 A

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(54) Abstract Title
Liquid crystal device

(57) A liquid crystal device has a nematic liquid crystal layer 12 between first and second alignment layers 14 and 16. The first and second alignment layers 14 and 16 have respective alignment directions which are mutually parallel. The nematic liquid crystal layer 12 has a negative dielectric anisotropy and is switchable between first and second, birefringent modes in which liquid crystal molecules in an intermediate region 12c of the liquid crystal layer 12 are in a splay state and in which the difference in optical retardation is (i) an odd number of half wavelengths for a transmissive mode device or (ii) an odd number of quarter wavelengths for a reflective mode device.

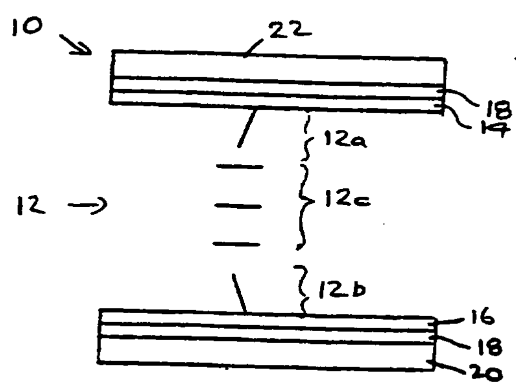

Figure 2C

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Figure 1

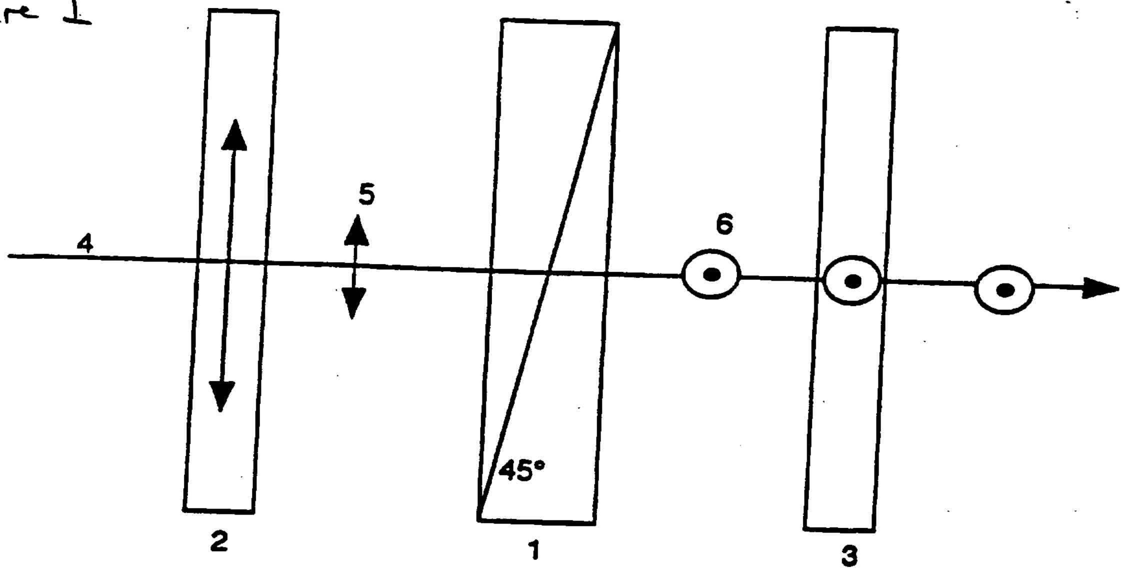


Figure 2A

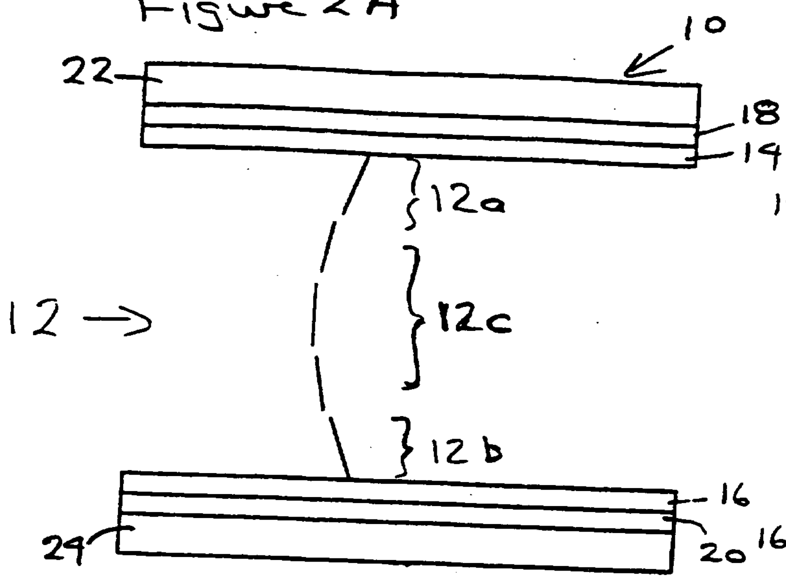


Figure 2B

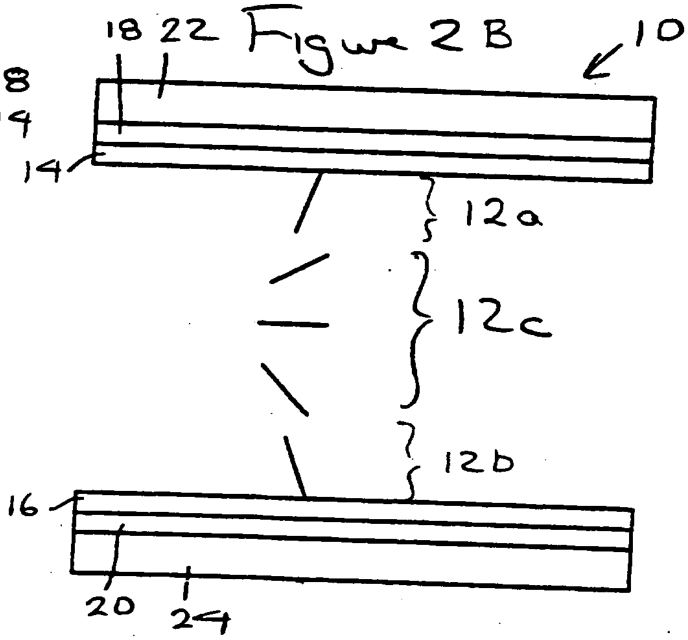


Figure 2C

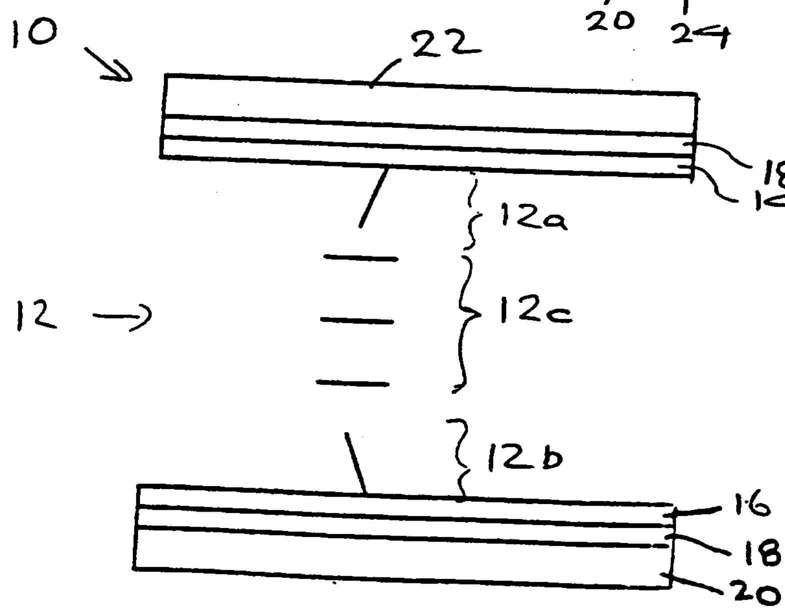


Figure 3

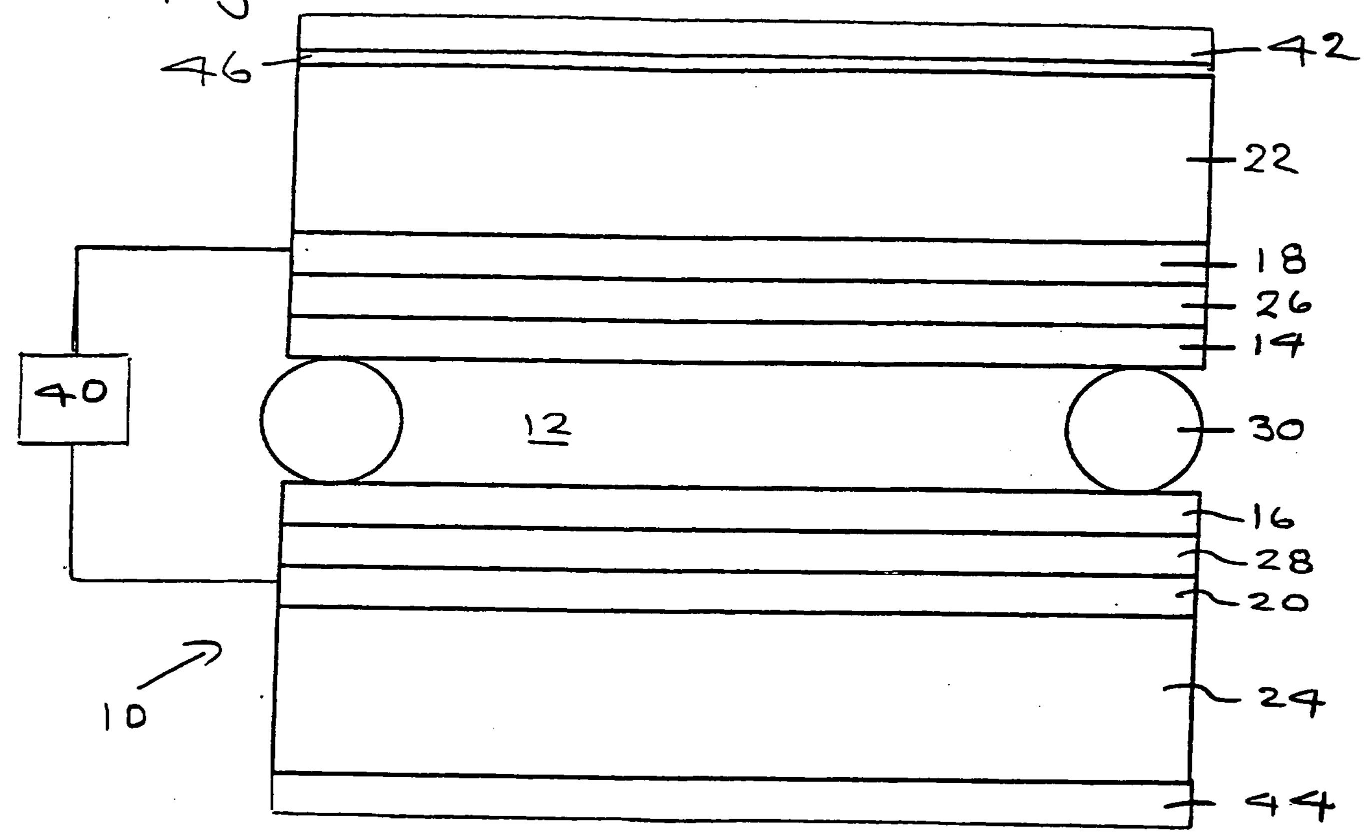


Figure 4

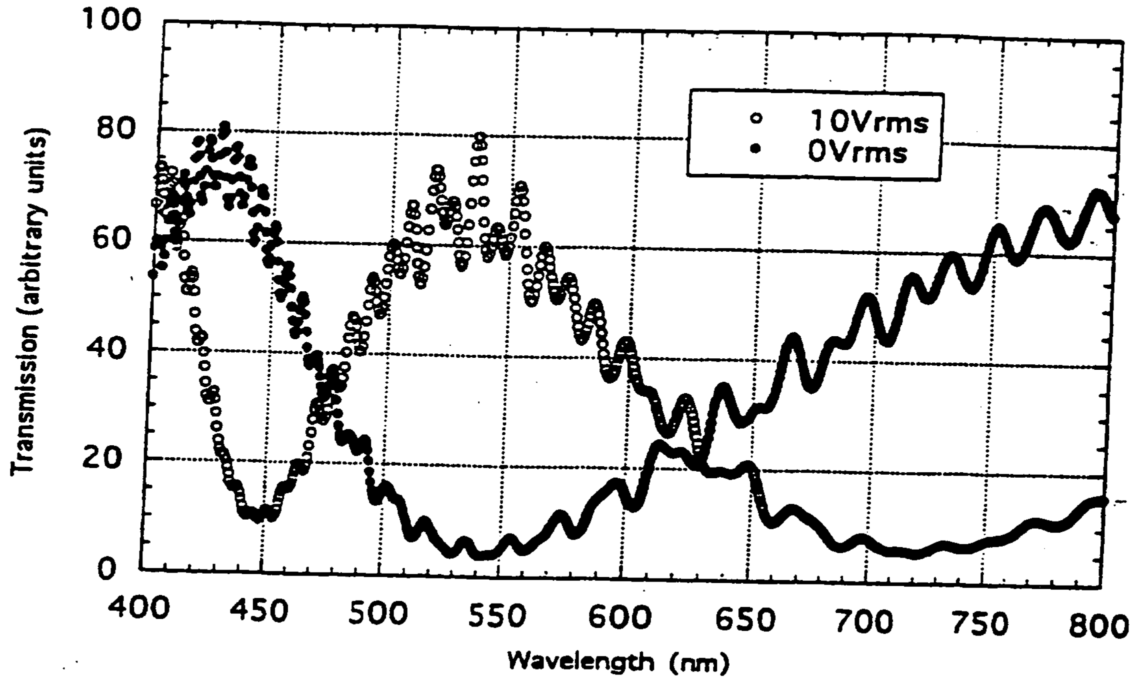


Figure 5A

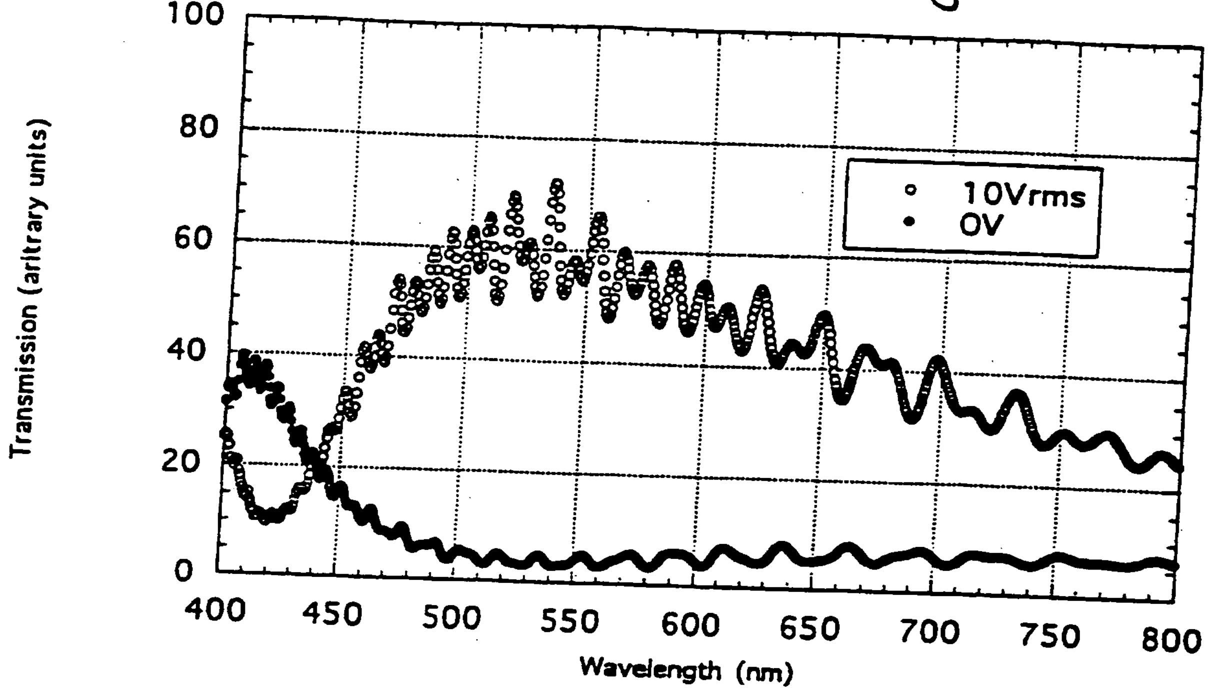


Figure 5B

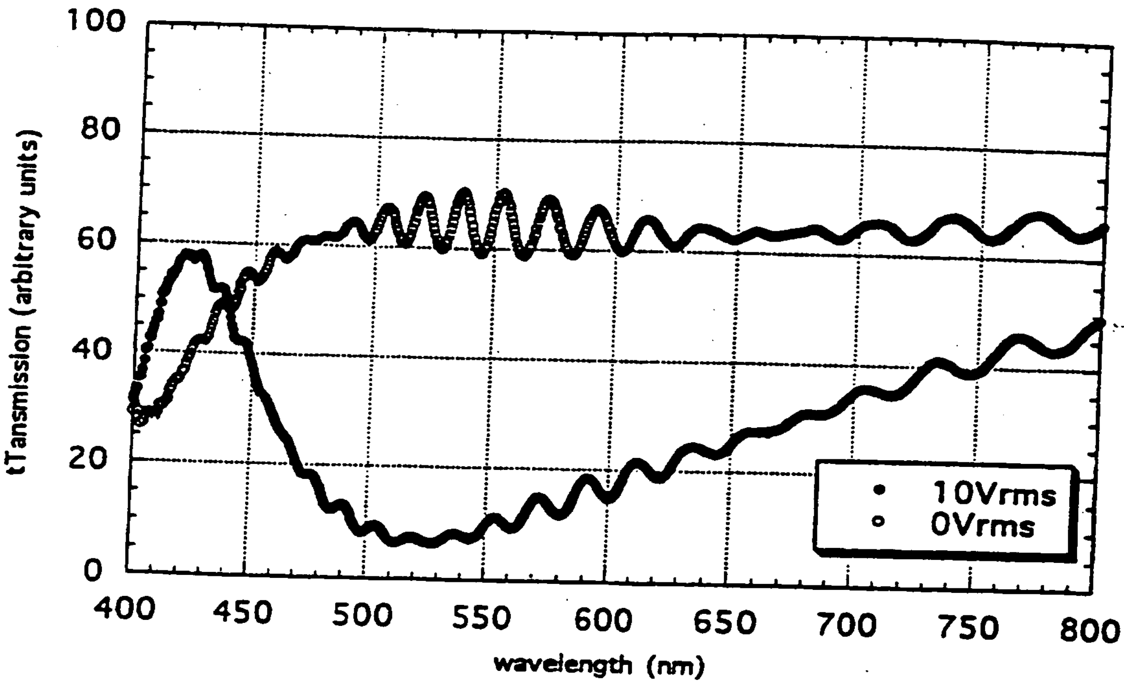


Figure 6

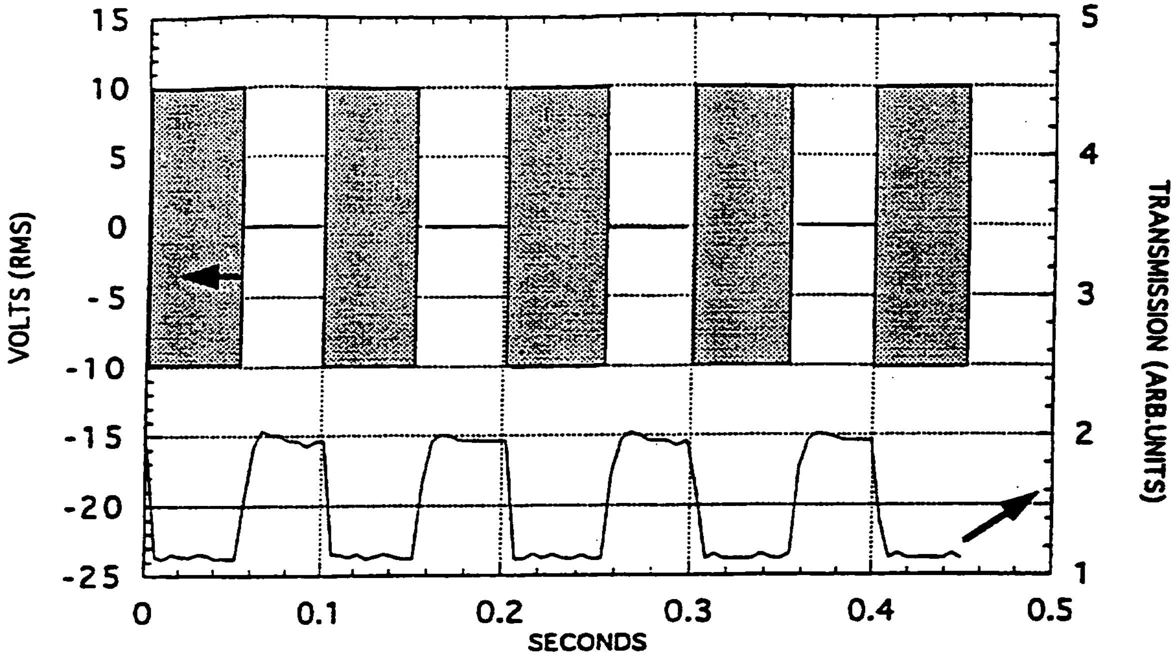


Figure 7A

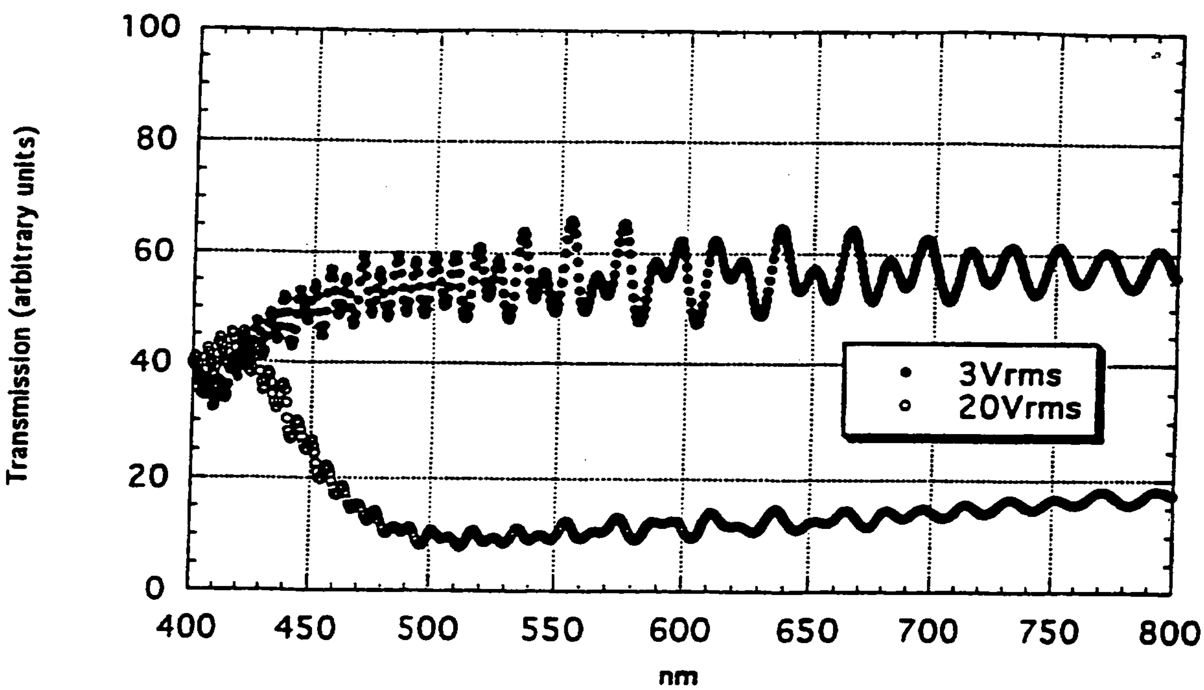


Figure 7B

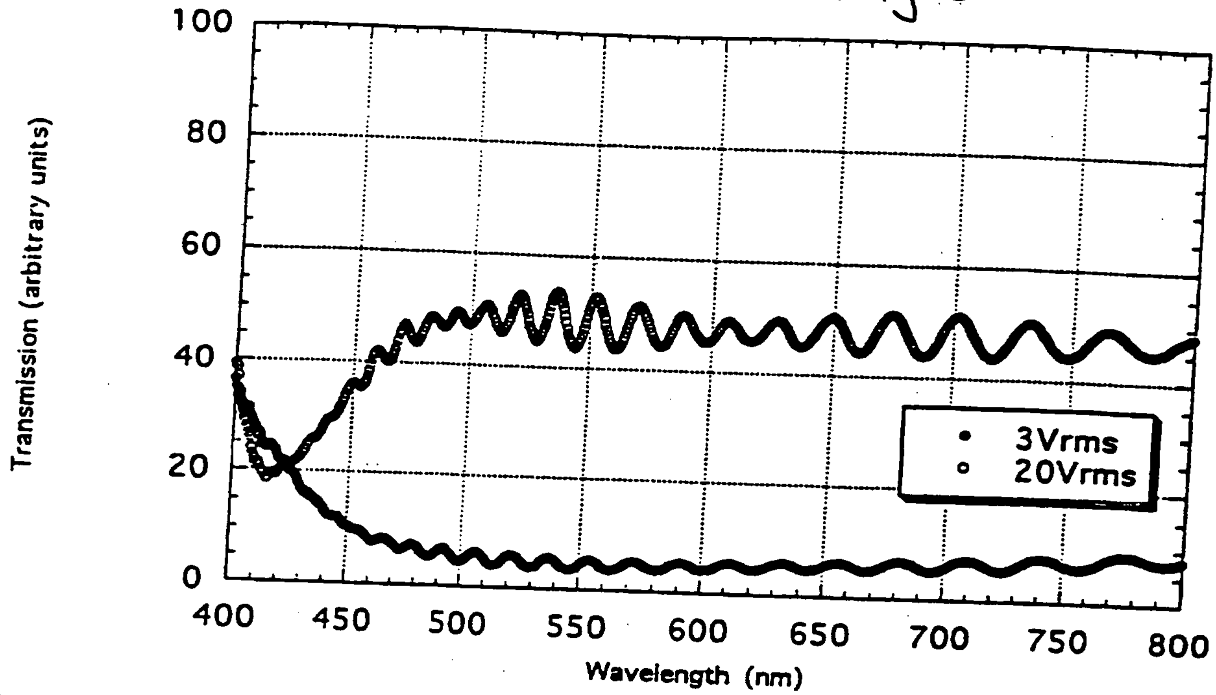


Figure 8

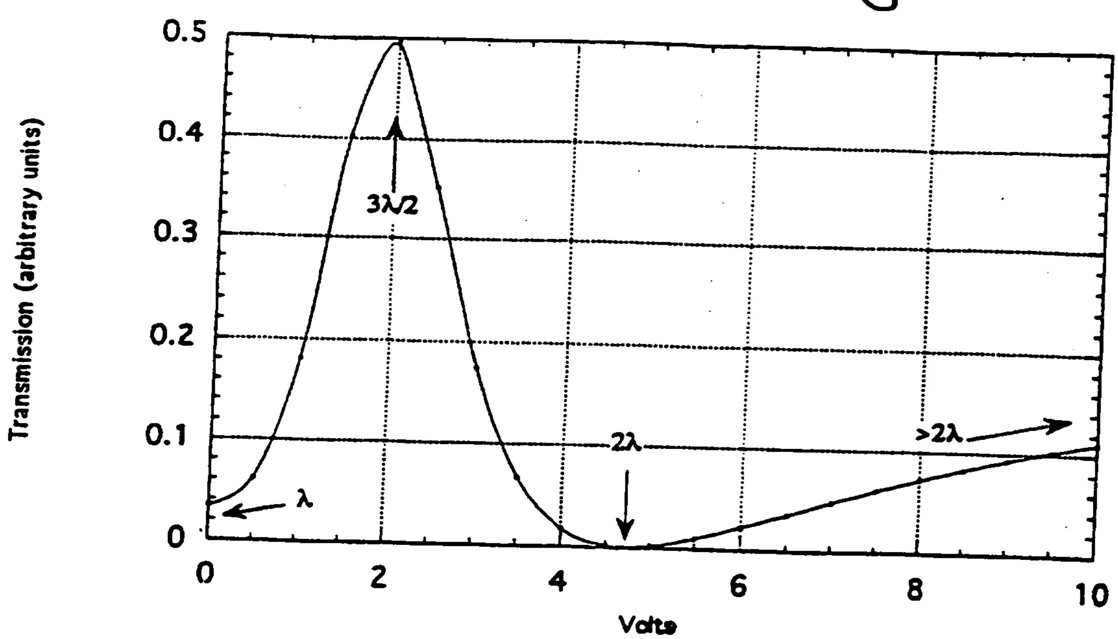


Figure 9

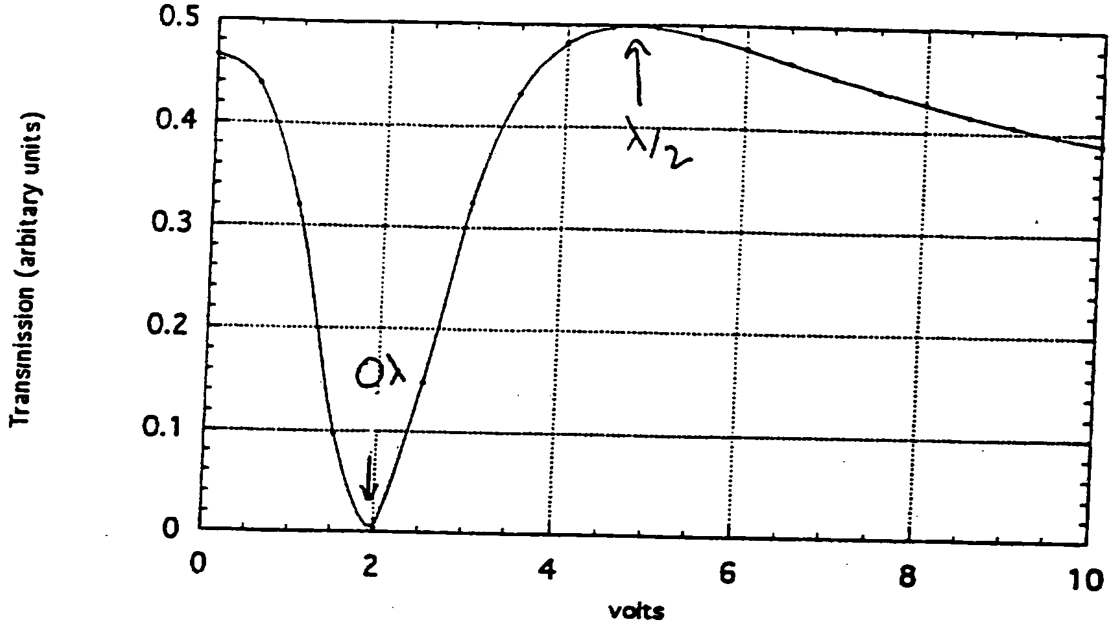


Figure 10

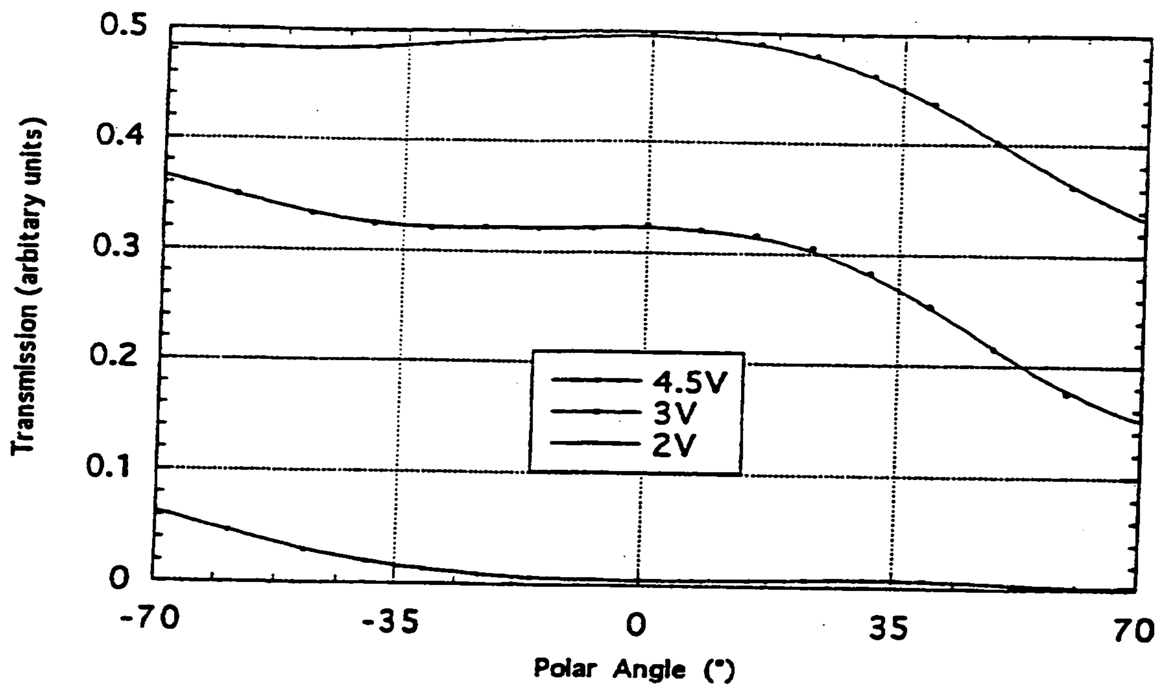


Figure 11

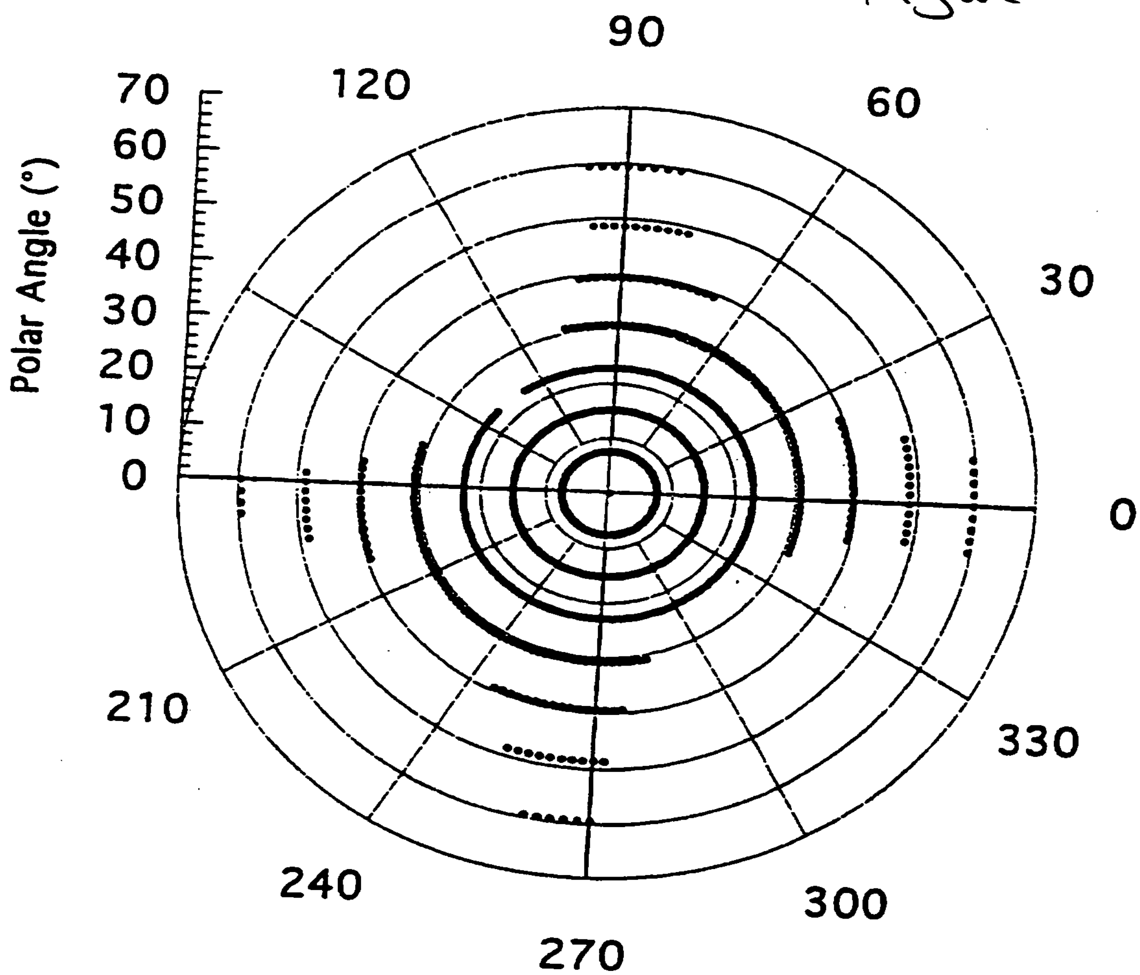


Figure 12

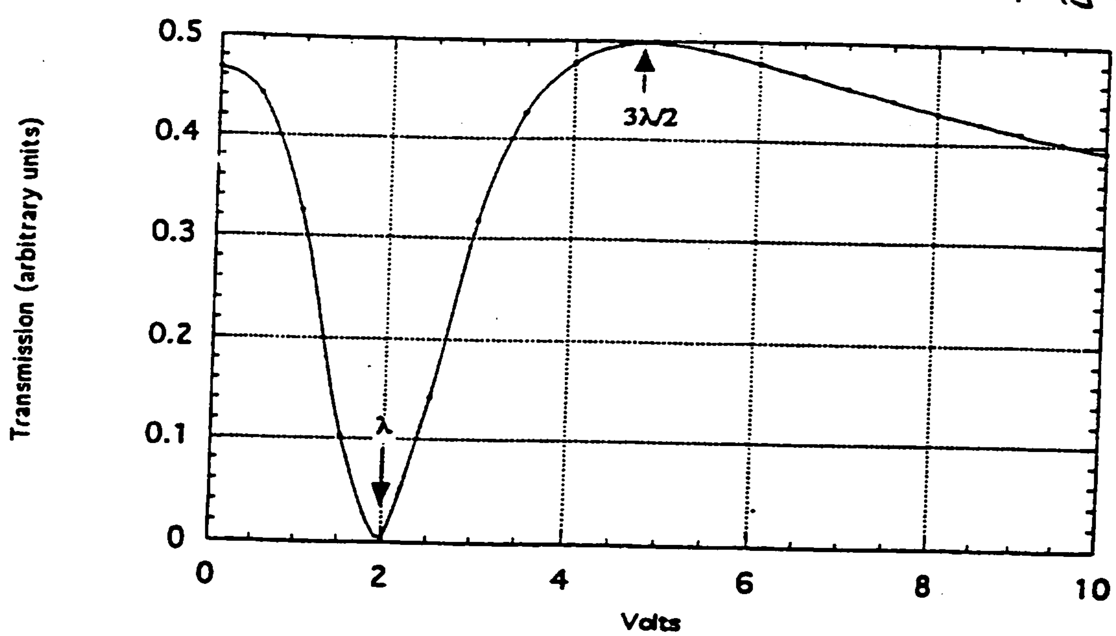


Figure 13

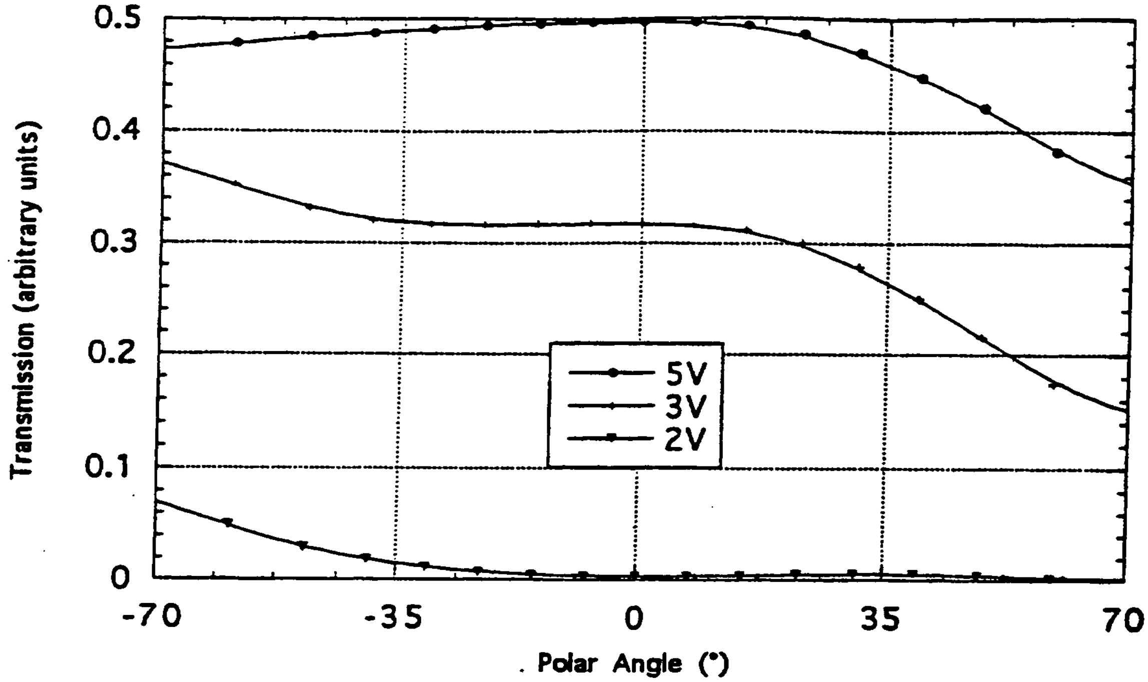


Figure 14

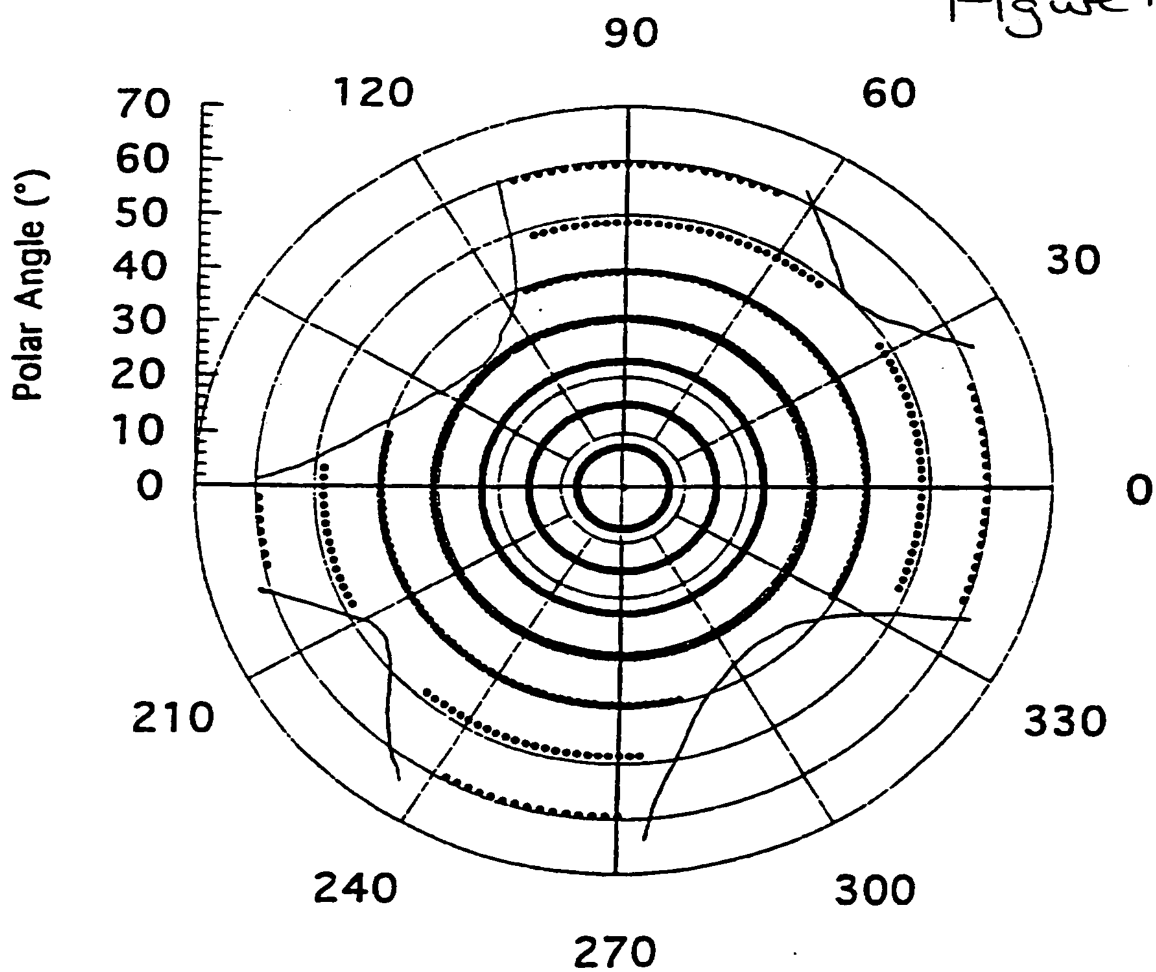


Figure 15

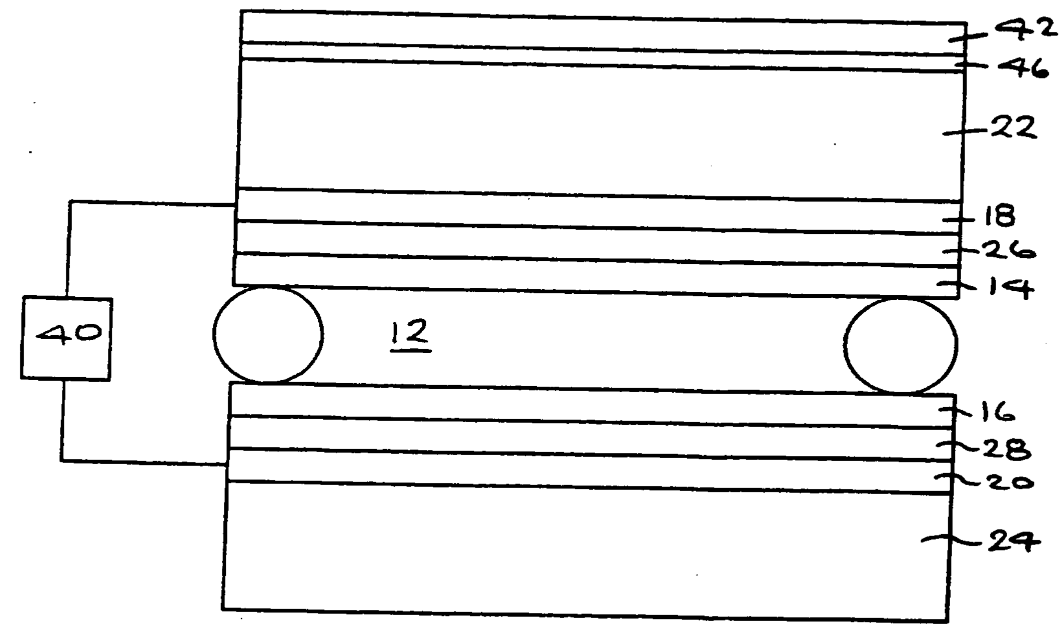


Figure 16

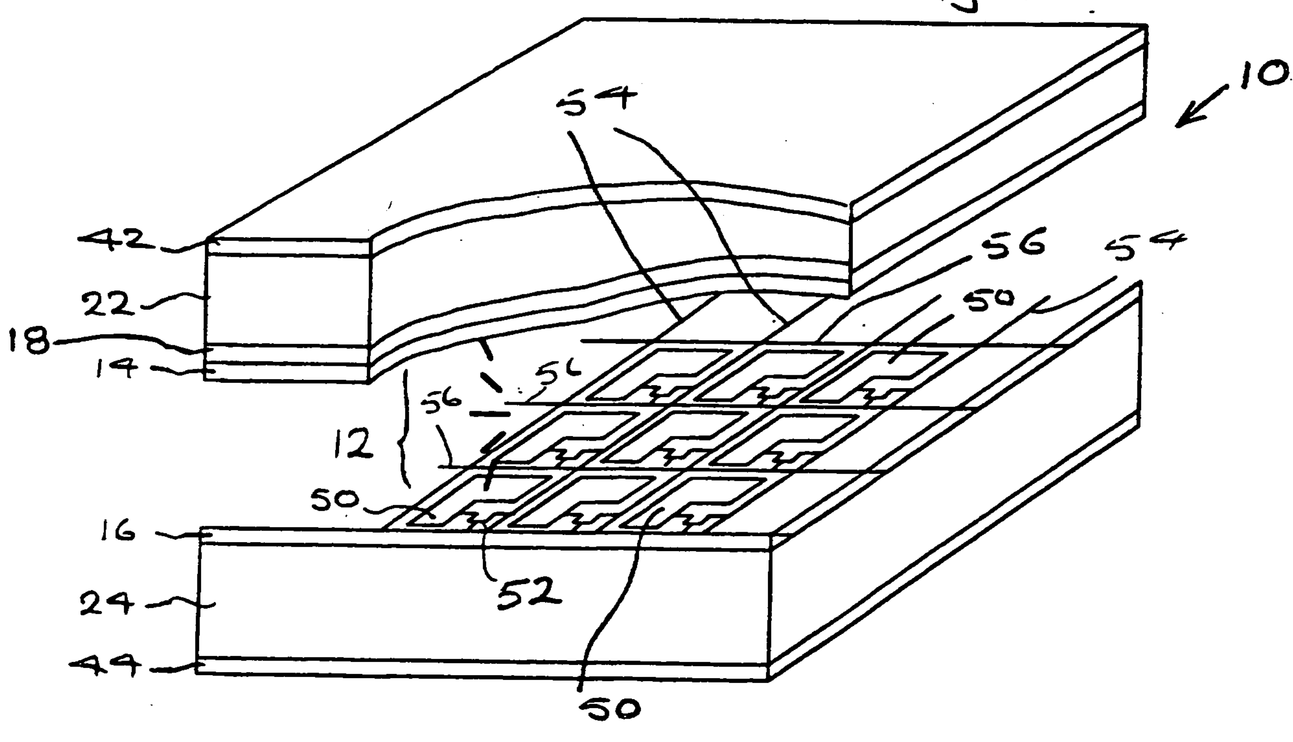


Figure 17

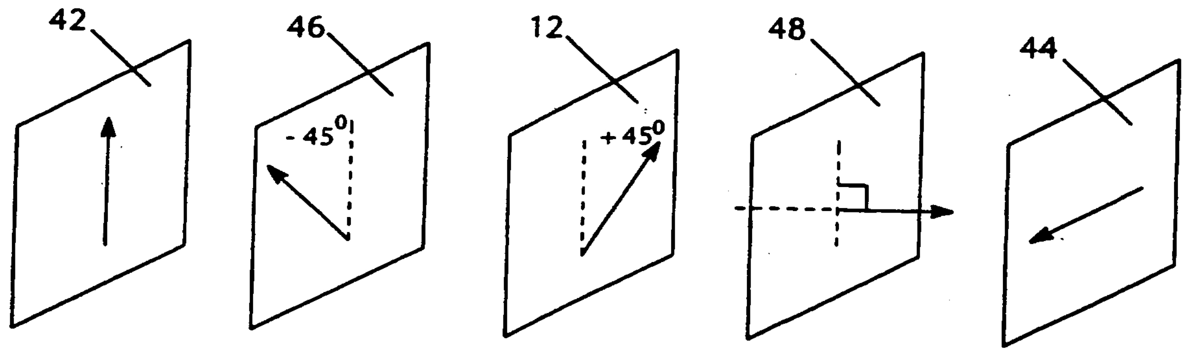
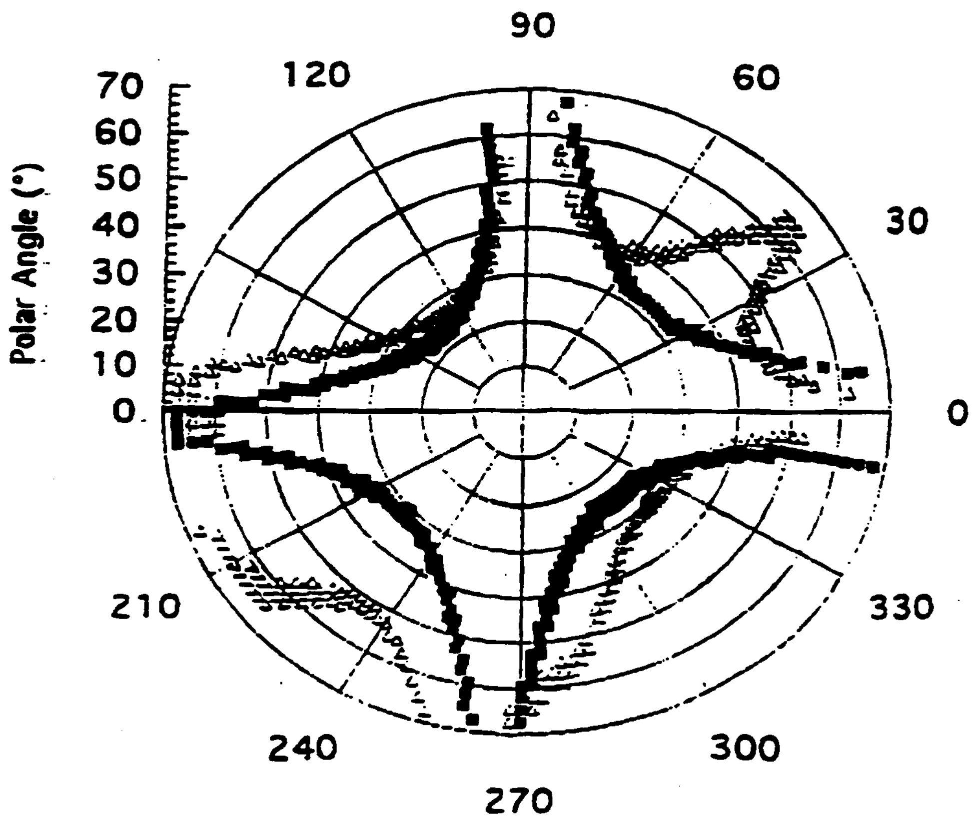


Figure 18



LIQUID CRYSTAL DEVICE

This invention relates to a liquid crystal device and is more particularly concerned with such a device which is capable of acting as an optical shutter. The device may be of the active-matrix type and has potential application in the field of pixellated LCD's for use in televisions including 3D televisions, computer displays, personal organisers etc.

US 4385806 discloses a liquid crystal display in which a nematic liquid crystal layer is disposed between glass plates coated with transparent conductive material to form electrodes. The nematic liquid crystal layer has positive dielectric anisotropy. The surfaces of the electrodes are rubbed so as to act as alignment layers for the liquid crystal molecules in contact therewith. In particular, the alignment layers are arranged such that the liquid crystal molecule pretilt angles at the alignment layer surfaces are anti-parallel to each other. In order to improve the off-axis viewing angle of such a display, at least two retardation plate devices are provided.

EP-A-0616240 discloses a liquid crystal display in which a nematic liquid crystal is disposed between first and second alignment layers which are treated so that the liquid crystal molecule pretilt angles are parallel to each other. The nematic liquid crystal layer has a positive dielectric constant anisotropy. The device includes at least one phase plate and the arrangement is such that (a) for operation in transmissive mode, the combined retardance of first said at least one phase plate and the liquid crystal layer is substantially equal to $(M+1)\ \lambda/2$ at a first operating voltage of the device and is substantially equal to $M\lambda/2$ at a second operating voltage of the device, or (b) for operation in reflective mode,

the combined retardance of said at least one phase plate and the liquid crystal layer is substantially equal to $(M+1)\lambda/4$ at a first operating voltage of the device and is substantially equal to $M\lambda/2$ at a second operating voltage of the device, wherein M is an integer and λ is a wavelength of optical radiation.

There is an increasing need for liquid crystal devices possessing the capability of both fast optical switching and good viewing angle characteristics.

It is therefore an object of the present invention to provide an improved liquid crystal device having the capability of fast optical switching and good viewing angle characteristics.

According to the present invention, there is provided a liquid crystal device comprising a nematic liquid crystal layer; and first and second alignment layers disposed on opposite sides of the liquid crystal layer, the first and second alignment layers having respective alignment directions which are mutually parallel; wherein the nematic liquid crystal layer has a negative dielectric anisotropy and is switchable between first and second birefringent modes in which liquid crystal molecules in an intermediate region of the liquid crystal layer are in a splay state and in which the difference in optical retardation is (i) an odd number of half wavelengths for a transmissive mode device or (ii) an odd number of quarter wavelengths for a reflective mode device.

For transmissive mode devices, first and second linear polarisers are usually provided on opposite sides of the liquid crystal layer. Such

polarisers may be arranged with their polarisation axes mutually parallel or mutually perpendicular.

For reflective mode devices, a linear polariser is usually provided on one side of the liquid crystal layer and a reflector is provided on the opposite side of the liquid crystal layer.

At least one fixed optical retardation or phase plate may be provided so that, with an appropriate combination of cell thickness, optical anisotropy of the liquid crystal material and arrangement of said at least one retardation or phase plate so as to subtract from the cell birefringence, the birefringence in the splay state can be made to modulate between $n\lambda/2$ and $(n+m)\lambda/2$ (where n is zero or a positive or negative integer and m is any odd integer) for a transmissive mode device. Preferably, the arrangement is such that the birefringence in the splay state modulates, in use, between substantially zero and a half-wave retardation.

In the case of a reflective mode device, the arrangement is such that the birefringence in the splay state modulates, in use, between $n\lambda/4$ and $(n+m)\lambda/4$ (where m and n are as defined above) and more preferably between substantially zero and a quarter-wave retardation.

An example of a liquid crystal material having negative dielectric anisotropy is ZLI4788-000 (Merck)

It is within the scope of the present invention for the nematic liquid crystal layer to be of restricted mobility such that the splay state is stable at a lower voltage state and most preferably remains stable at zero volts.

D.S. Fredley et al, Conference Record of 1994 International Display Research Conference, pages 480-483 disclose liquid crystal materials of restricted mobility. In order to produce such a material, a small percentage (typically ~ 1-2%) of a photocurable diacrylate monomer (e.g. a diacrylate material RM257 - Merck) is doped into a liquid crystal (LC), and the monomer is then polymerised whilst applying a voltage across the liquid crystal cell. The LC acts to align the monomer, and the oriented polymer network created during photopolymerisation in turn acts to orient the LC molecules. In this manner, once polymerisation has taken place, the applied voltage can be removed and the LC molecules tend to remain orientated as though the voltage were still present. The molecules retain sufficient mobility, however, that at higher voltages they can be reoriented further (such oriented systems of LC + polymer, wherein the LC retains some freedom of movement are sometimes called 'gels'). In this way, the necessity to apply a finite voltage and wait for the splay state to form is avoided.

It is preferred for the liquid crystal molecules in contact with the first and second alignment layers to have a high surface pre-tilt (typically about 80 to 90°), although if the ratio of the splay elastic constant to the bend and twist is chosen correctly, a wider range of pre-tilts can in principle be used.

A number of approaches to the production of high (~80-90°) pretilt surfaces may be employed. For example, the technique taught by T. Uchida et al, Japanese Journal of Applied Physics, Vol 19, No. 11, November 1980, pp 2127 - 2136, may be employed. This involves the oblique evaporation of SiO onto a glass substrate, followed by treatment

with a homeotropic surface coupling agent. Very light rubbing of homeotropic alignment surfaces can also be used.

Alternatively, in order to obtain high pre-tilt angles, at least one and preferably both alignment layers are formed from a mixture of first and second polymerisable liquid crystal monomers (hereinafter called "the first reactive mesogen" and "the second reactive mesogen"), wherein the second reactive mesogen has a lower polymerisation functionality than the first reactive mesogen.

The first reactive mesogen is preferably a liquid crystal molecule having a polymerisation functionality provided by at least one polymerisable moiety at each end thereof.

The second reactive mesogen is preferably a liquid crystal molecule having polymerisation functionality provided by at least one polymerisable moiety (more preferably, a single polymerisable moiety) at only one end thereof.

The polymerisation functionality may be provided by an acrylate group (including a methacrylate group), a vinyl ether group or an epoxy group. However, it is preferably provided by an acrylate group. In a preferred embodiment, the first reactive mesogen is a diacrylate and the second reactive mesogen is a monoacrylate.

The reactive mesogen mixture alignment layer may be formed using per se known techniques such as by spin-coating a mixture of the first and second reactive mesogens and a photoinitiator in a solvent or carrier onto a pre-formed alignment layer such as a rubbed polyimide layer.

It is found that the higher the proportion of the secondary active mesogen, the higher the pretilt angle which can be achieved up to a certain limit. The second reactive mesogen may be present in an amount of up to about 40 wt% of the total weight of the first and second reactive mesogens, more preferably about 5 to 40 or higher wt% and most preferably about 10 to 30 wt%. For very high pretilt angles (i.e. for use where low tilted-off homeotropic alignment is required), the second reactive mesogen may be present in an amount of about 20 to 30 % by weight.

In comparison to the well known twisted nematic liquid crystal switching mode, devices according to the present invention have a wider, more symmetric viewing angle and a faster switching time.

The angular variation in optical path length for a positive uniaxial sheet retarder with molecules lying in the plane of the sheet, is less than for a similar retarder with molecules oriented normal to the sheet.

The use of negative dielectric material ensures that, in the high voltage state, most of the molecules in the cell are aligned in the plane of the cell substrates. This has advantage of possessing improved viewing angle characteristics as compared with conventional birefringent devices using positive dielectric anisotropy materials for which molecules align normal to cell substrates in the high voltage state.

In the accompanying drawings:-

Figure 1 is a schematic view illustrating the principle of operation of a half-waveplate between mutually perpendicular linear polarisers;

Figures 2A to 2C are schematic views showing the states of liquid crystal molecules in a device according to the present invention at zero, relatively low and relatively high voltage states, respectively;

Figure 3 is a schematic view of various parts of an experimentally fabricated liquid crystal device used to generate the data shown in Figures 4 to 13;

Figure 4 is a graph of transmission vs. wavelength showing experimental data for a splayed nematic birefringent device according to the present invention between crossed polarisers,

Figure 5A is a graph similar to Figure 4 showing experimental data for a splayed nematic birefringent device with full-wave plate subtracting between crossed polarisers;

Figure 5B is a graph similar to Figure 5A showing experimental data for a splayed nematic birefringent device with full-wave plate subtracting between parallel polarisers;

Figure 6 is a graph similar to Figure 4 showing experimental data for optical switching of the splayed nematic birefringent device with full-wave plate subtracting between parallel polarisers;

Figure 7A is a graph similar to Figure 4 showing experimental data for a splayed nematic birefringent device with $3/2\lambda$-waveplate subtracting between crossed polarisers;

Figure 7B is a graph similar to Figure 4 showing experimental data for a splayed nematic birefringent device with 3/2λ-waveplate subtracting between parallel polarisers;

Figure 8 is a graph of transmission vs. voltages for a splayed nematic birefringent device between crossed polarisers;

Figure 9 is a graph similar to Figure 8 for a splayed nematic birefringent device fitted with a 793.4nm subtracting retarder and crossed polarisers;

Figure 10 is a graph showing the viewing angle characteristics of a splayed nematic birefringent device fitted with a 793.4nm subtracting retarder;

Figure 11 is a contrast ratio plot for the splayed nematic birefringent device fitted with a 793.4nm subtracting retarder;

Figure 12 is a graph similar to Figure 8 for a splayed nematic birefringent device fitted with a 266.1 nm subtracting retarder and crossed polarisers;

Figure 13 is a graph similar to Figure 10 for the splayed nematic birefringent device fitted with a 266.1 nm subtracting retarder and crossed polarisers;

Figure 14 is a graph similar to Figure 11 for the splayed nematic birefringent device fitted with a 266.1 nm subtracting retarder; and

Figure 15 is a view similar to Figure 3 of an alternative embodiment;

Figure 16 is a schematic view of an active matrix device according to the present invention;

Figure 17 is a schematic illustration of a further embodiment of splayed nematic birefringent device according to the present invention; and

Figure 18 is a contrast ratio plot (10:1 contrast lines) for the splayed nematic birefringent device of Figure 17.

Figure 1 shows the well known fact that a half-waveplate 1 (i.e. an optical retarder with retardation equal to half the wavelength of incident light) when placed between crossed first and second linear polarisers 2 and 3 will allow a ray of incident light 4 to pass through the second polariser 3. The action of the half-waveplate 1 is to rotate the polarisation axis of the light 5 from the first polariser 2 through an angle of 90° as indicated at 6 whence it can pass through the second polariser 3. A zero-wavelength (or, more generally, an $n=0,1,2,...$ wavelength) retarder has no effect on the polarisation state of the light and, if placed between crossed polarisers, will not allow transmission.

Figures 2A to 2C shows one embodiment of a splayed nematic birefringent device according to the present invention. The device comprises a liquid crystal cell 10 having a nematic liquid crystal layer 12 disposed between first and second mutually parallel alignment layers 14 and 16. Mutually parallel electrodes 18 and 20 are provided outside the alignment layers 14 and 16. Mutually parallel transparent glass substrates 22 and 24 are disposed outwardly of the electrodes 18 and 20. For transmission mode devices, linear polarisers (not shown) are disposed on opposite sides of the illustrated cell 10 and are either mutually

parallel or mutually perpendicular. For reflective mode devices, a linear polariser and a mirror (also not shown) are provided on opposite sides of the illustrated cell 10. The first and second alignment layers 14 and 16 are such as to impart a high surface pretilt (typically ~80-90°) to liquid crystal molecules in surface regions 12a and 12b of the layer 12 which are in contact with the respective alignment layers 14 and 16. The first and second alignment layers 14 and 16 are rubbed so that their alignment directions are mutually parallel.

The nematic crystal layer 12 has a negative dielectric anisotropy (i.e. the molecules prefer to align with their short axes along an electric field). As a result of this and as a result of the mutually parallel alignment directions of the alignment layers 14 and 16, in the zero voltage state (Figure 2A), the liquid crystal molecules in the layer 12 adopt a bend configuration across the thickness of the layer 12, this being the lowest energy state compatible with the requirement of high pretilt at the surfaces of the layers 14 and 16. As the voltage is increased (Figure 2B), the liquid crystal molecules in an intermediate region 12c of the layer 12 realign to lie with their short axes along the direction of the applied field so as to produce a splay state as illustrated. In the splay state at low voltages only a thin part at the centre of the intermediate region 12c has its molecules aligned perpendicular to the applied electric field (Figure 2B), thus, since the most molecules are predominantly perpendicular to the glass substrates 22 and 24, the birefringence of the layer 12 is small for light incident normally on the cell. At higher voltages, as more of the molecules in the intermediate region 12c reorient to lie with their short axes along the field direction (Figure 2C), the birefringence increases. By modulating the applied voltage between a relatively low value and a relatively high value, the birefringence of the layer 12 can be made to

modulate between a relatively low and high value respectively. Through a combination of the correct choice of cell thickness, material optical anisotropy and the use of external retarders (see examples below) to subtract from the cell birefringence, the birefringence in the splay state can be made to modulate between substantially zero and a half-wave retardation (or more generally $n\lambda/2$ and $(n+m)\lambda/2$ where n is any integer and m is any odd integer) i.e. producing an optical shutter when used with two optical polarisers as described above.

The nematic crystal layer 12 may be of the restricted mobility type as described above by incorporating about 1-2% of a photocurable diacrylate monomer (e.g. RM257) into the liquid crystal material (e.g. ZLI 4788-000, Merck), and then polymerising the monomer whilst applying a voltage across the liquid crystal cell. Once polymerisation has taken place, the applied voltage can be removed and the liquid crystal molecules tend to remain orientated as though the voltage was still present. However, the liquid crystal molecules retain sufficient mobility that, at higher voltages, they can be reoriented further to produce the above-described effect.

An experimental splayed nematic birefringent device as shown in Figure 3 was constructed. Parts of the device of Figure 3 which are similar to those of the device of Figure 2 are accorded the same reference numerals. In this device, however, additional alignment layers 26 and 28 were provided outwardly of but in contact with the alignment layers 14 and 16, respectively, and a spacer 30 was provided to space the alignment layers 14 and 16 so that the liquid crystal layer 12 is about 5 μm thick. The electrodes 18 and 20 were formed of an ITO coating on the glass substrates 22 and 24.

In order to produce the alignment layers 14 and 26 and 16 and 28, the two glass substrates 22 and 24 were first coated with ITO (indium tin oxide) to form the electrodes 18 and 20. The ITO-coated glass substrates 22 and 24 were spin-coated with a layer of polyimide (PI2555, DuPont), baked at 250°C for 1 hour, and unidirectionally rubbed with a nylon cloth to produce a pretilt alignment direction, thereby to produce the alignment layers 26 and 28 on the respective glass substrates 22 and 24. A mixture of organic reactive mesogen materials RM257 + 30% (wt:wt) RM305 was dissolved in 15 parts (by weight) of toluene. A small amount (1% by weight) of a photoinitiator (in this example, Daracur 4265 - Ciba Geigy) was included, and the solution spun at 5 krpm for 10 seconds onto the polyimide- and ITO-coated glass substrates 22 and 24. The RM layers were cured by exposure to UV light under a nitrogen atmosphere to form the alignment layers 14 and 16 on top of the layers 26 and 28, respectively. The two substrates 22 and 24 were then assembled into the liquid crystal cell 10 and glued, producing a measured cell gap of 5.2 μm between the layers 14 and 16. The coated substrates 22 and 24 were mutually orientated so that the alignment directions of the alignment layers 14 and 16 were mutually parallel. The cell was capillary filled with the negative dielectric anisotropy material ZL14788-000 (Merck) to produce the liquid crystal layer 12. The RM layers 14 and 16 produced a pretilt of the order of 80° with this material.

Once filled, a square wave voltage (10 Vrms, 1 kHz) was applied across the cell by means of the electrodes 18 and 20 by a variable voltage generator 40 and a transition observed from the zero-volt bend state to a splay state. The splay state was observed to be metastable at low voltage, allowing the voltage to be reduced from 10 Vrms to 0 V with

the equilibrium bend state only growing back in order a period of minutes.

Figure 4 shows a graphical plot of the transmission of the cell vs. wavelength, with the liquid crystal layer 12 in its splay state and held with the alignment direction of the alignment layers 14 and 16 at an angle of 45° relative to the polarisation axes of linear polarisers 42 and 44 which are on opposite sides of the cell 10 and which, in this particular example, were crossed, i.e. with their polarisation axes mutually perpendicular. It is observed that at 10 Vrms the cell behaves as approximately a $3/2\lambda$-waveplate at 525 nm, and at 0 V as a λ-waveplate for 525 nm light. A commercial retardation film 46 which, in this embodiment produced an optical retardation of 525 nm (i.e. a 'full waveplate'), was placed on top of the cell 10, with the fast axis of the retarder 46 crossed with respect to the alignment direction of the alignment layers 14 and 16, thereby subtracting 525 nm from the retardation of the cell 10.

Figures 5A and 5B show the consequences for crossed and parallel polarisers 42 and 44, respectively. Crossed polarisers 42 and 44 produce 'normally black' mode operation, and parallel polarisers 42 and 44 produce 'normally white mode'.

Figure 6 shows the optical response (curve 1) when driving this cell 10 between the 0 and half-wave retardation states. The measured switching times of the cell were 3ms (when switching from 0 to 10 V) and 9 ms (when switching from 10 V to 0 V).

Since the splay state is only metastable at 0 V, it is preferable to subtract even more retardation from the cell 10 and work between higher voltages where the splay state is more stable. Thus, in a further embodiment, external retarders were arranged so as to act approximately as a subtracting $3/2\lambda$-waveplate. This enabled $-\lambda/2$ to 0 wave operation to be achieved using 3 Vrms and 20 Vrms, respectively. This is shown in Figures 7A and 7B for crossed and parallel polarisers, respectively.

Figures 8 to 14 show modelled results for a splayed nematic birefringent device. The material constants (refractive indices, elastic constants, dispersion, dielectric anisotropy etc.) are those for E7 at room temperature, however the sign of the dielectric anisotropy has been inverted, to model a negative dielectric anisotropy material. Computer modelling was performed using the well known numerical methods by D. W. Berreman in Phil. Trans. R. Soc. Lond., A309, pp 203-216 (1983 and in J. Opt. Soc. Am., 62, 505 (1972). The cell has a thickness of 5 μm, a pretilt of 85° and is held between crossed polarisers. The liquid crystal is in its splayed configuration. Figure 8 shows transmission vs. voltage for the cell for normally incident 525 nm light. At 2 Vrms, the cell has an optical thickness of approximately 3/2-wavelengths, and 2-wavelengths at ~4.5 Vrms.

By inserting a subtracting 1.5113-waveplate (of RM257) between the polarisers, in front of the cell, the transmission vs. voltage curve of Figure 9 is produced. At 2 V, the retardation is now substantially zero, and is a half-wave at ~4.5 V.

Figure 10 shows polar viewing angle characteristics of this cell at zero azimuthal angle.

Figure 11 shows the domain of points for which the contrast ratio between the 2 V and 4.5 V states exceeds 10:1

In the above description, Figure 8 showed the retardation vs. voltage for a splayed nematic birefringent device, and Figure 9 showed how a subtracting 793.4nm retarder could be used to allow 0 λ to $\lambda/2$ switching. In general, it is possible to consider operation of the splayed nematic birefringent device between any two retardation levels of substantially $n\lambda/2$ and $(n+m)\ \lambda/2$, where n is zero or a positive or negative integer and m is an odd integer. Figure 12 shows the transmission vs. voltage for the splayed nematic birefringent device shown previously in Figure 8, but with a subtracting 266.1 nm waveplate placed before the cell, between crossed polarisers. Driving the cell between 2 V and 5 V then corresponds to λ to $3/2\lambda$ operation. The viewing angle characteristics of this device are shown in Figure 13, whilst the contrast ratio plot is shown in Figure 14.

It is preferable that a medium/high information content matrix-addressed liquid crystal display in accordance with the present invention employs active matrix technology (e.g. TFT, MIM or PALC technology)

Referring now to Figure 15, the device illustrated therein is similar to that of Figure 3, except that it is a reflective mode device rather than a transmissive mode device. Thus, in the device of Figure 15, the linear polariser 44 is omitted and glass substrate 24 forms a mirror. Alternatively, the linear polariser 44 may be replaced by a separately formed mirror. In use, the retardation of the cell is switched between 0 and substantially a quarter-wave retardation (or more generally between

$n\lambda/4$ and $(n+m)\lambda/4$, where n is zero or a positive or negative integer and m is an odd integer), thus producing an optical shutter in reflection.

Referring now to Figure 16, there is illustrated an active matrix display device in which parts which are similar to those of Figure 3 are accorded the same reference numerals. In this embodiment, electrode 18 is a sheet electrode formed of a transparent, uniform ITO (indium tin oxide) layer on glass substrate 22, and the electrode 20 of Figure 3 is replaced by a series of shaped (in this example L-shaped) pads 50 delineating pixels of the device. Each pixel has an associated thin film transistor (TFT) element 52 lying at the intersection of "source" and "gate" electrode lines 54 and 56, respectively. Thus, it is possible to address each pixel individually in a manner which is well known per se in the art, so as to apply an appropriate voltage across that portion of the liquid crystal layer 12 which is associated with that pixel.

In the case of a colour display, the device would include an array of colour filters on one of the glass substrates 22, 24, as is well known per se in the art. Optical retarders and/or optical compensation layers may also be affixed to either or both of the glass substrates 22, 24. In the place of the TFT elements, diodes or an ionising gas (a so-called PALC device) may be employed, again in a manner well known per se in the art.

Referring now to Figure 17, the optical orientations of the various optical elements of an embodiment of a splayed nematic birefringent device are schematically illustrated therein. Those optical elements which are similar to the those in the previously described devices are accorded the same reference numerals. Linear polarisers 42 and 44 are mutually crossed, and

retardation film 46 has its fast optic axis in the plane of the film 46 at an angle of - 45° with respect to the polarisation axis of polariser 42 and produces a subtracting optical retardation of 486.0 nm. The retardation film 46 may be formed using the RM257 material as described above. The splayed nematic birefringent liquid crystal layer 12 is 5 μm thick and has its optical axis disposed at an angle of +45° with respect to the polarisation axis of polariser 42. In this embodiment, the device further includes a homeotropic film 48 which is 3.5 μm thick and whose fast optic axis extends perpendicularly to the plane of the film 48. Such film 48 may be produced using the RM257 material as described above such that the reactive mesogen molecules extend are perpendicular to the plane of the film and then "locked" in this orientation by polymerisation of the reactive mesogens. In such an arrangement, the film 48 has a uniform refractive index in the plane of the substrate and a different refractive index perpendicular to such plane. This homeotropic film 48 is provided to improve the viewing angle.

In simple terms, this is because the molecules in the film 48 extend generally perpendicularly with respect to the molecules in the layer 12c when the device is subjected to a relatively high voltage (see Figure 2C). In this condition, when viewing the device at the normal incidence angle, the molecules in the region 12c can be seen because they are "side-on" to the viewer, whereas the molecules in the film 48 cannot be seen because they are "end-on" to the viewer. As the viewing angle departs from the normal, the molecules in the region 12c are seen more "end-on" (a change in birefringence), but this is compensated for by the molecules in the film 48 which are seen more "side-on". The effect of this will be apparent from the contrast ratio plot of Figure 18 shows 10:1 isocontrast lines (ie. where the contrast ratio is 10(±1):1) for the device of Figure 17 wherein the 3.5

μm thick homeotropic film 48 having the refractive indices of the RM257 material is (a) present (▵) and (b) absent (■). It can be seen from Figure 18, the presence of the film 48 improves the viewing angle.

Such a homeotropic film layer having molecules which extend perpendicularly out of the plane of the layer may be used to improve viewing angle in other liquid crystal display devices where liquid crystal molecules contributing to birefringence in the liquid crystal layer extend substantially perpendicularly with respect to such molecules in the homeotropic layer.

CLAIMS

1. A liquid crystal device comprising a nematic liquid crystal layer; and first and second alignment layers disposed on opposite sides of the liquid crystal layer, the first and second alignment layers having respective alignment directions which are mutually parallel; wherein the nematic liquid crystal layer has a negative dielectric anisotropy and is switchable between first and second birefringent modes in which liquid crystal molecules in an intermediate region of the liquid crystal layer are in a splay state and in which the difference in optical retardation is (i) an odd number of half wavelengths for a transmissive mode device or (ii) an odd number of quarter wavelengths for a reflective mode device.

2. A liquid crystal device as claimed in claim 1, which is a transmissive mode device and which further comprises first and second linear polarisers on opposite sides of the liquid crystal layer, and wherein said difference in optical retardation is an odd number of half wavelengths.

3. A liquid crystal device as claimed in claim 2, further comprising at least one fixed optical retarder arranged so as to subtract from the cell birefringence, whereby the birefringence in the splay state modulates, in use, between $n\lambda/2$ and $(n+m)\lambda/2$ (where n is zero or a positive or negative integer and m is any odd integer).

4. A liquid crystal device as claimed in claim 3, wherein the birefringence in the splay state modulates, in use, between substantially zero and a half-wave retardation.

5. A liquid crystal device as claimed in claim 1, which is a reflective mode device and which further comprises a linear polariser and a mirror on opposite sides of the liquid crystal layer, and wherein said difference in optical retardation is an odd number of quarter wavelengths.

6. A liquid crystal device as claimed in claim 5, further comprising at least one fixed optical retarder arranged so as to subtract from the cell birefringence, whereby the birefringence in the splay state modulates, in use, between $n\lambda/4$ and $(n+m)\lambda/4$ (where n is zero or a positive or negative integer and m is any odd integer).

7. A liquid crystal device as claimed in claim 6, wherein the birefringence in the splay state modulates, in use, between substantially zero and a quarter-wave retardation

8. A liquid crystal device as claimed in any preceding claim, wherein the first and second alignment layers produce a surface pre-tilt of about 80 to 90°.

9. A liquid crystal device as claimed in any preceding claim, wherein at least one of the alignment layers is formed from a mixture of first and second reactive mesogens, and wherein the second reactive mesogen has a lower polymerisation functionality than the first reactive mesogen.

10. A liquid crystal device as claimed in claim 9, wherein the first reactive mesogen is a liquid crystal molecule having a polymerisation functionality provided by at least one polymerisable moiety at each end thereof.

11. A liquid crystal device as claimed in claim 9 or 10, wherein the second reactive mesogen is a liquid crystal molecule having polymerisation functionality provided by at least one polymerisable moiety at only one end thereof.

12. A liquid crystal device as claimed in claim 9 or 10, wherein the second reactive mesogen is a liquid crystal molecule having polymerisation functionality provided by a single polymerisable moiety at only one end thereof.

13. A liquid crystal device as claimed in claim 9 or 10, wherein the polymerisation functionality is provided by an acrylate group.

14. A liquid crystal device as claimed in claim 13, wherein the first reactive mesogen is a diacrylate and the second reactive mesogen is a monoacrylate.

15. A liquid crystal device as claimed in any one of claims 9 to 14, wherein the second reactive mesogen is present in an amount of up to about 40 wt% of the total weight of the first and second reactive mesogens.

16. A liquid crystal device as claimed in any one of claims 9 to 14, wherein the second reactive mesogen is present in an amount of about 5 to 40

17. A liquid crystal device as claimed in any one of claims 9 to 14, wherein the second reactive mesogen is present in an amount of about 10 to 30 wt%.

18. A liquid crystal device as claimed in any preceding claim, wherein the nematic liquid crystal layer includes a cured monomer which serves to stabilize the splay state.

19. A liquid crystal device as claimed in any preceding claim, further including a homeotropic viewing angle compensating layer.

20. A liquid crystal device as claimed in any preceding claim, which is an active matrix liquid crystal display device.

21. A liquid crystal device as claimed in claim 1, substantially as hereinbefore described with reference to the accompanying drawings.

Application No: GB 9712378.0
Claims searched: 1 to 21

Examiner: G M Pitchman
Date of search: 27 August 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G2F (FCD)

Int Cl (Ed.6): G02F 1/139

Other: ONLINE: EDOC WPI JAPIO INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	EP 0616240 A1	(SHARP)-see abstract and claims 15 to 18	1-6
Y	EP 0433999 A2	(STANLEY ELECTRIC)-see abstract	1-6
Y	EP 0421432 A1	(TOSHIBA)-see abstract and page 5 line 27	1-6

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